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CONCEPT DESIGN OF HAYATE: SMALL SATELLITE FOR SUPPORTING ANTARCTIC GEOPHYSICAL OBSERVATIONS

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Abstract: This paper presents the results of conceptual design of a small communication satellite (HAYATE) for supporting research in Antarctica and remote islands. The HAYATE satellite collects environmental data from unmanned probes located on the Antarctic ice plate and also transmits data from Syowa Station in Antarctica to Japan and the United States. Through the satellite mission analyses, we confirmed that the HAYATE satellite would be able to gather data for GPS baseline analysis and to observe environmental changes over a wide area. Moreover, we analyzed heat, power, attitude control, and vibrations of the satellite, and defined the performance requirements for the satellite system.

key words: small satellite, concept design, store and forward, Antarctic observation, unmanned probe

1. Introduction

As witnessed at the Kyoto Environmental Conference in 1998, the interest in finding solutions to the earth's environmental problems is great. Antarctica represents one of the most important sites for monitoring the earth's environment, and thus it is desired to enhance observation capabilities at these locations through international cooperation. However, it is difficult to carry out long term observations by human personnel over such a vast area as Antarctica because of the harsh climate. And it is desired to establish an unmanned observation method. Even this approach is difficult due to the problem of gathering large amounts of data from unmanned probes dispersed over a large area. Until now, the Automatic Weather Station (AWS) has been used in Antarctica (STEARNS and WEIDNER, 1992). The AWS unit measures meteorological data which are transmitted to polar-orbiting satellites equipped with the ARGOS (a satellite-based system for gathering environmental data telemetry and geopositioning) data collection system. Recently, these probes are being expected to perform more functions, for example, GPS based measurement and gravity measurement. These data make it possible to calculate the large-scale dynamics of Antarctic ice plate as well as the mass budget of the ice sheet (MAENO *et al.*, 1995). But it is difficult for the AWS/ARGOS system to cope with the necessary amount of data transmission. The data length is only up to 256 bits in the

ARGOS system, not enough to transmit such data.

Return of Japanese Antarctic data to Japan presently depends on retrieval missions by the icebreaker ship SHIRASE which comes to the area only once a year. This means that researchers are sometimes obliged to wait more than a year before starting detailed analyses of the precious observation data. Solving this problem is very important from the point of view of real-time monitoring of the earth's environment. There are some space-bone data transmission methods for real-time monitoring: INMARSAT (4 satellites) orbiting in GEO (Geosynchronous orbit) has been used for the communication between ships, and, in recent years, Iridium (66 satellites in LEO (Low-Earth orbit)) has been developed for commercial satellite communication. However, these systems are not appropriate for transmission of very large amounts of data. If we transmit about 100 GB/year data through the systems, the cost is \$4.8 million for INMARSAT or \$27 million for Iridium.

In response to the needs identified above, we propose the following satellite missions: 1) to provide a platform for gathering data from probes placed at various points in Antarctica and/or from observation team members in the area; 2) to provide a platform for transmitting observation data from Syowa Station to Japan (Tokyo Institute of Technology) and the U.S. (Arizona State University). These goals can be satisfied by deploying a small communications satellite over the Antarctic region and using this satellite to transmit data back to Japan and the international community in general support of Antarctic research activities. The satellite would of course be widely available to the international research public. This paper outlines these missions and presents the concept design of the HAYATE satellite.

2. Characteristics of the Missions and Expected Results

For the satellite, the mission that we propose this time is very simple, "store and forward". The HAYATE satellite collects telemetry data from probes placed in Antarctica and receives observation data from Syowa Station. HAYATE stores the received data in memory and transmits the stored data to Tokyo Institute of Technology (Titech) ground station and Arizona State University (ASU) ground station. HAYATE also collects data from some probes placed on uninhabited islands and other places (such as high mountains) in the world. The satellite is planned to be developed mainly by university students. The followings are expected results of the missions.

(1) To obtain important data about the large-scale dynamics of the Antarctic ice plate and the changes over a wide area of the environment in Antarctica by collecting telemetry data (GPS and various environmental data) regularly from the probes.

(2) To transmit large quantities of Antarctic observation data throughout the year (100 GB maximum), so that a better and more current assessment of the Antarctica environment can be made.

(3) GPS data from probes placed in far-remote areas such as uninhabited islands and high mountains compose part of the GPS Earth observation network. In particular, the installation of probe on Okino-torishima island in Japan is important because Okino-torishima is the only island in the part of the Philippine sea plate which is believed to have caused the Tokai earthquake and the Nankai earthquake.

(4) The possibility of obtaining public funds and the fact that the satellite will be designed and operated under university leadership will contribute greatly toward reducing the overall cost of the mission.

3. Mission Statement

3.1. Telemetry data collected from probes located on the Antarctic ice plate

In this mission, the HAYATE satellite collects environmental data from some probes placed at various points in Antarctica and delivers them to users worldwide. Each probe transmits data at about 400 MHz, and the data rate is 19.2 kbps.

The following is the flow of this mission.

(i) Each probe transmits the telemetry data (GPS, gravity, weather etc.) in accordance with TDMA (Time Division Multiple Access).

(ii) HAYATE stores the received data in memory.

(iii) HAYATE transmits the collected data to the ASU and Titech ground stations after

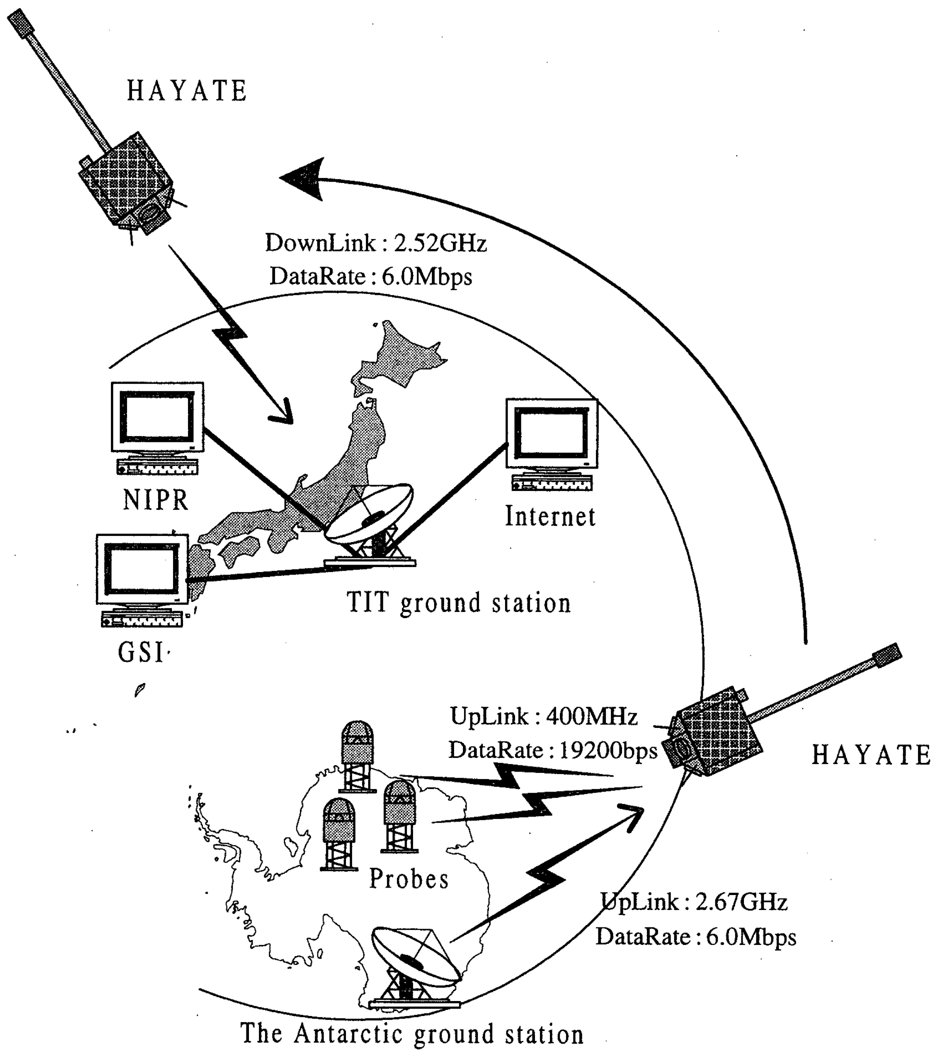

Fig. 1. Mission outline.

receiving a 'send data' command.
(iv) The data are processed and made available to the public through the Internet.

3.2. Data transmission from Syowa Station to ground stations in Japan and the U.S.

HAYATE also needs to receive observation data from the Antarctic ground station. The amount of data from the ground station is large. So the uplink frequency is about 2.67 GHz, and the data rate is 6.0 Mbps. HAYATE then transmits the stored data to a ground station in Japan at about 2.52 GHz with data rate of 6.0 Mbps. This mission makes it possible to transmit over 100 GB/year from Syowa Station to Japan/US.
(i) Data are transmitted from Syowa Station to the HAYATE satellite when communication conditions with the satellite are good.
(ii) HAYATE stores the received data in memory and sends a confirmation to Syowa Station.
(iii) HAYATE transmits the stored data to the ASU and Titech ground stations.
(iv) The data are processed and made available to the public through the Internet.

Figure 1 shows these HAYATE missions.

4. Overview of the HAYATE Satellite

The design of HAYATE was analyzed for compatibility as a piggy-back satellite atop a Japanese H-II launcher (Larson and Wertz, 1994). In orbit, 4 UHF antennas oriented toward the Earth and a gravity gradient boom for attitude stabilization extend in opposite directions. Table 1 presents a preliminary estimate of HAYATE parameters and characteristics, and Fig. 2 shows the appearance of the HAYATE satellite.

5. HAYATE Satellite Subsystem

5.1. Communication subsystem

The communication subsystem consists of a S-band (2.52/2.67 GHz) communication system (4 Micro strip antennas, S-band transmitter/receiver) and an UHF communication system (4 UHF antennas and UHF receiver). Table 2 presents the result of communica-

Table 1. Characteristics–HAYATE satellite.

Satellite	Weight: 41 kg Size: 0.5×0.5×0.5 m
Orbit	Altitude: 700 km Inclination: 98 deg (polar orbit) Period: about 100 min
Attitude control	Gravity gradient stabilization Magnetic attitude control
Power	18.5 W (average), 72.7 W (maximum)
Communication	Data transmission, telemetry, command: S band Data collection from probes: UHF band
Life time	4 years

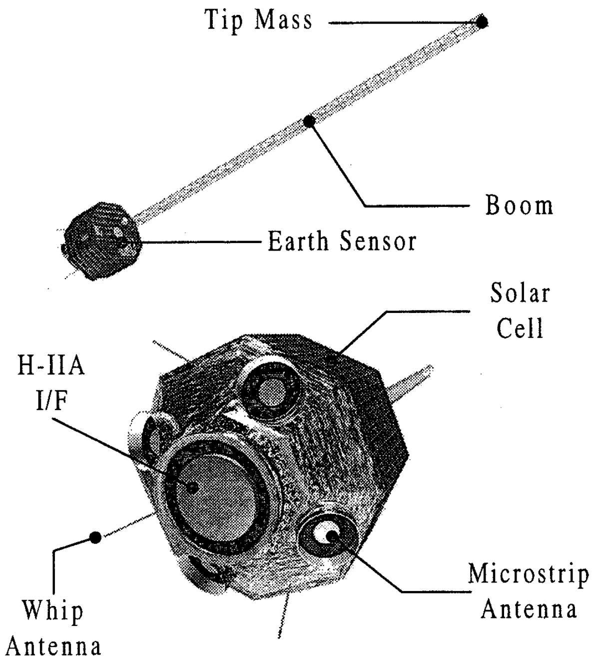

Fig. 2. HAYATE satellite.

Table 2. The result of the link budget.

	A	B	C
Frequency [GHz]	2.52	2.67	0.4
Transmitter power [W]	10	30	5
Transmit antenna beamwidth [deg]	60	3.93	
Transmit antenna gain [dB]	3.99	32.16	0
Equiv. isotropic radiated power [dBW]	12.99	45.93	5.99
Receive antenna beamwidth [deg]	4.17	60	
Receive antenna gain [dB]	31.68	3.99	0
Data rate [Mbps]	6	6	19.2×10^{-3}
Eb/No [dB]	12.30	13.35	11.51
Bit error rate	10^{-7}	10^{-7}	10^{-5}
Required Eb/No [dB]	5.6*	5.6*	4.5*
Margin [dB]	5.70	6.75	6.01

A: From HAYATE to Titech ground station, B: From the Antarctic ground station to HAYATE, C: From probes to HAYATE
* Error correction technique is BPSK+Viterbi soft decoding

tion link budget for the HAYATE missions in the worst communication condition (TANAKA, 1998). Then, we calculate the relationship between the communication link margin† and probe's elevation (Fig. 3). As the result of these calculations, we found that HAYATE will be able to communicate in all missions.

† link margin: describes valiability of the communication link in numerical values. Communication may not work correctly when the link margin is less than 3 dB.

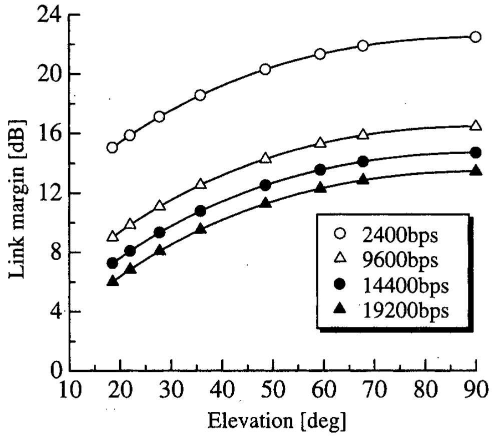

Fig. 3. Link margin and probe elevation.

5.2. Attitude determination and control subsystem

The HAYATE satellite employs body-mounted antennas and needs to orient one body face to point the antennas toward the nadir. From these mission requirements, we decided to use gravity gradient stabilization with active magnetic control for roll and pitch axis control and use a passive damper for the yaw axis (WERTZ, 1978). Hardware for attitude determination and control consists of Earth horizon sensors, digital Sun sensors, a 3-axis magnetometer, a gravity gradient boom, magnetorquer rods and a wheel damper. The gravity gradient boom is often used for various satellite systems including small satellites.

5.3. Thermal control subsystem

The purpose of the thermal control subsystem is to maintain all satellite components within allowable temperature limits. We estimated the approximate temperature of the satellite by the Network Method (GILMORE, 1994). The result of this analysis confirmed that HAYATE can maintain all the elements of its system within their temperature limits for all mission phases.

5.4. Power subsystem

The HAYATE satellite is powered by twelve 6 ampere-hour NiCd batteries charged by 45 W GaAs solar panels (body mounted). We found that the satellite will be able to obtain enough power until the end of its lifetime (4 years later).

5.5. Command and data handling subsystem

The Command and Data Handling (C&DH) subsystem consists of on-board computers, a data recorder, a command decoder and other components. We are examining the possibility of using an OBC with a 32 bit CPU which was developed by NASDA. This satellite mounts a magnetic hard drive as the data recorder. We provide a 2 GB capacity so as to satisfy the mission objective.

5.6. Structure subsystem

The structural configuration of the HAYATE satellite was determined by considering individual subsystems and overall mission requirements. The resulting shape is an octagonal piped structure. Consideration has been given to inertia effects when designing the lay-out of subsystems. Aluminum honeycomb is used as the main structural material.

6. Ground Systems

6.1. Ground station

The HAYATE satellite is controlled from the Titech ground station in Japan and the ASU ground station in the U.S. The Titech ground station has a parabola antenna (1.8 m diameter) and satellite tracking system. We assume that a ground station equipped with a 2.0 m diameter antenna will be installed at Syowa Station.

6.2. Probe

Probes are unmanned observation platforms placed at various points in Antarctica. The probes are powered by batteries charged by solar panels and operated on batteries for more than one year. They measure not only various meteorological data but also GPS data. In order to measure the large-scale dynamics of the Antarctic ice plate, a probe must sample data every 10 min and send 100 kB of data a day. To meet such requirements, each probe transmits data at about 400 MHz, and the data rate is 19.2 kbps. Each data length is up to 12 kB. Probes transmit it with TDMA. HAYATE will be able to

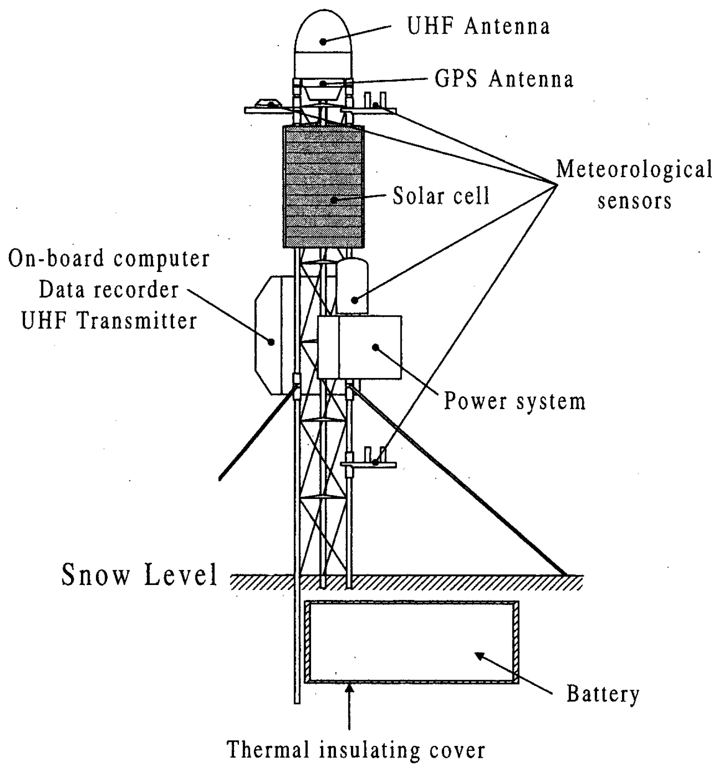

Fig. 4. Unmanned probe.

receive more than 15 bursts of data a day from each probe. These data make calculation of large-scale dynamics of Antarctic ice plates and calculation of the mass budget of the ice sheet possible. Figure 4 shows an example of probes. Batteries are buried in snow to avoid temperature change. This probe measures air temperature, wind speed, wind direction and air pressure. The probe also transmits housekeeping data of itself.

7. Conclusions

We have proposed a satellite to support wide area environment observations and accomplished conceptual design of the satellite. We have defined the mission requirements for satellite subsystems. From the results of mission analysis, we have confirmed that the HAYATE satellite is able to gather enough data for GPS baseline analysis from probes and also to transmit large quantities of Antarctic observation data throughout the year (100 GB maximum) from Syowa Station to Japan and the U.S.

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